Stress-Induced Deficits in Working Memory and Visuo-Constructive Abilities in Special Operations Soldiers

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Background: *Pre-clinical and clinical studies have shown acute stress may impair working memory and visuo-spatial ability. This study was designed to clarify the nature of stress-induced cognitive deficits in soldiers and how such deficits may contribute to operational or battlefield errors.*

Methods: *One hundred eighty-four Special Operations warfighters enrolled in Survival School completed pre-stress measures of dissociation and trauma exposure. Subjects were randomized to one of three assessment groups (Pre-stress, Stress, Post-stress) and were administered the Rey Ostereith Complex Figure (ROCF). All subjects completed post-stress measures of dissociation.*

Results: *ROCF copy and recall were normal in the Pre- and Post-stress groups. ROCF copy and recall were significantly impaired in the Stress Group. Stress group ROCF copy performance was piecemeal, and ROCF recall was impaired. Symptoms of dissociation were negatively associated with ROCF recall in the Stress group. Baseline dissociation and history of traumatic stress predicted cognitive impairment during stress.*

Conclusions: *Stress exposure impaired visuo-spatial capacity and working memory. In rats, monkeys, and humans, high dopamine and NE turnover in the PFC induce deficits in cognition and spatial working memory. Improved understanding of stress-induced cognitive deficits may assist in identification of soldiers at risk and lead to the development of better countermeasures.*

Key Words: Cognition, dissociation, military performance, survival school, pre-frontal cortex, trauma exposure

In previous investigations we have reported on alterations in perception, cognition, and memory among active duty personnel exposed to the high-intensity stress of Survival School training. Exposure to acute stress resulted in symptoms of dissociation (alterations of one's perception of body, environment, and the passage of time), problem-solving deficits (as measured by objectively assessed military performance), and marked inaccuracies in memory (as measured by eyewitness identification) (Morgan et al 2000a; Morgan et al 2001a; Morgan et al 2001b; Morgan et al 2004). The current investigation was designed to better define and characterize these stress-induced alterations. An enhanced understanding of the way stress affects perception, cognition, and memory is important because many battlefield errors (e.g., friendly fire incidents, collateral damage, etc.) have been linked to a decline in cognitive operations (Belenky et al 2000).

The Rey Ostereith Complex Figure (ROCF) drawing task is a standardized neuropsychological test that indexes visual perception, visuo-spatial organization, motor functioning, and memory (Loring et al 1990; Lezak et al 2004). It has well-established norms for both the copy and the recall phases of the test. Furthermore, its ease of administration makes the ROCF an ideal tool for assessing cognitive capacities in naturalistic settings, such as Survival School. The ROCF is a complex figure (Figure 1) that incorporates 36 different elements. When taking the test, subjects are instructed to copy the figure as accurately as possible. Normative data suggest that the copying strategy varies between children and adults (Waber and Holmes 1985, 1986). Whereas younger children commonly copy the figure in a piecemeal fashion, post-pubertal children and adults copy the figure using a configurational approach (i.e., the large central rectangle is drawn first, followed by the addition of details).

After the copy phase of the test, subjects are asked to reproduce the figure from memory (the recall phase). Normative data have been established for recall performance at 1 min, 3 min, and 25 min. Factor analytic studies suggest that the copy phase of the ROCF measures visuo-constructive ability, whereas the recall phase involves memory (Waber and Holmes 1985, 1986).

Deficits in ROCF performance have been documented in patients with Alzheimer's disease (Berry et al 1991), Parkinson's disease (Cooper et al 1991), Huntington's disease (Fedio et al 1979), poly-drug abuse (Rosselli and Ardila 1996), mild (Leininger et al 1990), moderate and severe head injuries (Poulton and Moffitt 1995), and epilepsy (Poulton and Moffitt 1995). ROCF performance deficits have also been demonstrated in patients suffering from psychiatric illnesses such as post-traumatic stress disorder (Uddo et al 1993) and major depression (Myers and Meyers 1995).

Currently, little data exist about the impact of acute psychological stress on ROCF performance in healthy humans. Hoffman and Al Absi (2004) evaluated the impact of a social stress test (i.e., public speaking task) on ROCF performance. Although stress exposure elicited significant alterations in measures of psychophysiology and mood, no ROCF deficits were observed (Hoffman and Al Absi 2004). Although interesting, these findings may not be directly applicable to real-world stress-related events. Laboratory stressors do not elicit neuro-biological, perceptual, and cognitive alterations comparable with those observed in soldiers undergoing Survival School training (Morgan et al 2000b). As such, Survival School represents a unique venue in which to examine the impact of realistic acute stress in humans.

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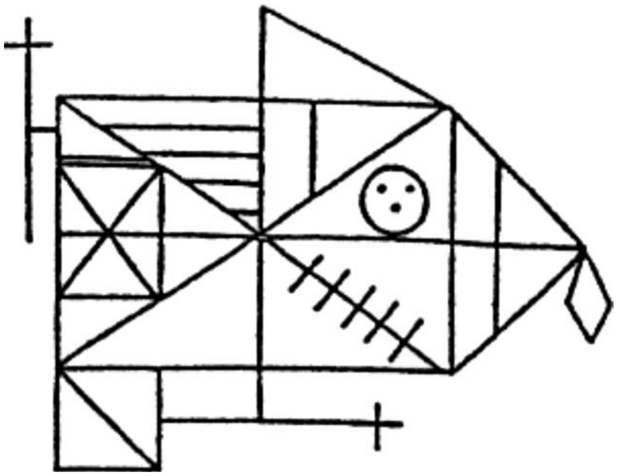

Figure 1. The Rey Ostereith Complex Figure (ROCF). In the administration of the test, subjects are shown the figure and asked to copy it while it is in full view. Next the figure is taken away, and after a designated time period (1-min, 3-min, or 5-min delay for immediate recall), subjects are asked to reproduce the figure from memory.

Military Survival School training is one of the most rigorous forms of training experienced by special operations military personnel. The training is based on the U.S. Military Code of Conduct and is designed to prepare warfighters for the possibility that they might be trapped in enemy territory, pursued by enemy forces, and captured and detained as prisoners of war. The methodology employed in this study has been reported in extensive detail elsewhere (Morgan et al 2000a, 2000b, 2001a, 2002, 2004). However, a brief description will be given to facilitate an understanding of the data.

The training is rigorous and modeled after experiences of American prisoners of war (POWs) from World War II and the Korean, Vietnam and Gulf wars. The course is designed to provide individuals with code of military conduct training as well as specific skills that may enhance their chances of surviving behind enemy lines and to return home with honor. The stress experienced by subjects during the confinement phase of survival school training produces neurobiological alterations on par with those documented in individuals exposed to real-world, threat-to-life experiences (Morgan et al 2000b).

The course is divided into didactic and experiential phases. The didactic phase comprises classroom lectures. During these lectures, students are instructed on how to find food, water, and shelter and are taught how to adhere to the U.S. Military Code of Conduct if ever captured and held as a prisoner of war. The experiential phase comprises an evasion exercise followed by confinement in a mock POW camp. During the evasion phase, students are pursued by mock-enemy forces and they try to avoid detection; During the mock captivity phase, they experience physical and psychological stress similar to those experienced by former POWs (i.e., food and sleep deprivation, exposure to stressful interrogations). At the conclusion of the experiential phase, students participate in a debriefing day where they review their performance and learn from their mistakes. After this debriefing, they graduate.

Because the level of stress experienced by Survival School participants is far greater than one can apply to participants in the traditional laboratory setting, the venue provides a unique opportunity to study the impact of realistic, acute stress on human cognition. Based on our previous investigations, we had several a priori hypotheses. We hypothesized that 1) ROCF recall performance, but not copy performance, would be significantly reduced by exposure to acute stress; and 2) ROCF recall during stress would be negatively associated with stress-induced symptoms of dissociation.

Materials and Methods

Subjects in the Study

A total of 184 of 200 consecutively recruited male, active duty personnel [mean age 23 years, standard deviation (SD) = 4.1] were the subjects of this study. One hundred thirty subjects (69.9%) were single, and 54 (29%) were married. Overall, 166 subjects were men; 18 were women. As designated by their military operational specialty, 92 subjects were Navy pilots, 14 subjects were Marine aviators, and 78 were air wing support personnel. Recruitment of subjects was conducted by the investigators (CAM, AD) at Fleet Aviation Specialized Operational Training Group, Atlantic Fleet (FASOTRAGRULANT), Naval Air Station, Brunswick, Maine. All subjects were informed that their decision to participate would not enhance or diminish their status or performance in Survival School training (CAM and AD). All subjects gave written informed consent; study approval was from Yale University and from VA Connecticut (IRB, Protocol 0006).

As per survival training course requirements, all subjects provided documentation of medical clearance before enrollment. All subjects were free of illicit substances. After enrollment, subjects were randomly assigned to one of three study groups, which corresponded with the conditions under which they would be given the working memory task (ROCF: the Pre-stress ROCF group; the Stress ROCF group; the Post-stress ROCF group). None of the subjects in this study had previously been exposed to the ROCF task.

Assessment of Subjects

Baseline. A baseline assessment was conducted on all subjects during the didactic phase of the course and on the second day of classroom activities. At approximately 4:30 PM, subjects assembled in the classroom and completed two self-report instruments: the Brief Trauma Questionnaire (BTQ) (Schnurr et al 1999) and the Clinician-Administered Dissociative States Scale (CADSS). (Bremner et al 1998) The BTQ is a valid self-report instrument that assesses history of exposure to potentially traumatic events. The questionnaire consists of 10 questions regarding exposure to types of trauma (for example, natural disasters, child physical abuse, sexual abuse, muggings, assaults, etc.). The BTQ is structured such that subjects responding in the affirmative to one of the questions are then given the opportunity to respond to two additional questions: Did you fear for your life? Were you seriously injured physically? These additional prompts are designed to assess whether the potentially traumatic event may meet DSM-IV criteria for qualifying as a “traumatic event.” Endorsement of “serious physical injury” and/or “fearing for one’s life” is interpreted as fulfilling DSM-IV criteria as a traumatic event. The BTQ is scored in a manner to reflect the total number and types of trauma exposure as well as whether the DSM-IV criteria for traumatic stress exposure has been met.

After this instrument, subjects completed a modified self-report version of the CADSS to rate their symptoms of dissociation during the classroom phase. The CADSS assesses the frequency and intensity of state symptoms of dissociation. The items of the instrument are designed to assess how perceptually "in touch" (or "out of touch") an individual is, vis-a-vis his or her environment, during specific conditions (nonstressed; stressed). Although some items on the scale ask about one's sense of physical self (e.g., "Do you feel as if you are looking at things outside of your body?" "Do you feel as if you are watching the situation as an observer or spectator?"), other items ask about cognitive or perceptual distortions (e.g., "Do colors seem to be diminished in intensity?" "Do sounds almost disappear or become much stronger than you would have expected?" "Do you space out or in some way lose track of what is going on?" "Do you see things as if you were in a tunnel, or looking through a wide angle photographic lens?"). The self-report scale contains 19 items, each of which is rated by subjects on a likert-type scale of 0 (not at all) to 4 (extremely). A total score of 76 is possible.

After completing the BTQ and CADSS, subjects randomized to the Stress and Post-Stress RCOF groups exited the classroom. Subjects randomized to the Pre-stress ROCF group remained seated. Subjects remained silent and did not engage in conversation with one another, nor were they allowed to assist one another during the ROCF task. Subjects were given a packet containing the ROCF printed on an 81/2 × 11-inch sheet of paper; two 8 1/2 × 11-inch blank sheets of paper; and two pencils, each of which was a different color. Subjects were instructed to begin the ROCF copy task. Approximately 1 min into the copy task, subjects were instructed to switch from the pencil they were using to the second pencil they had been given. After completion of the copy task, all copies and ROCF figures were collected. Subjects were then instructed to reproduce the drawing as precisely as possible (the recall phase). When they had completed this task, the drawings were collected.

Stress Assessment. Subjects assigned to the Stress ROCF group were administered the ROCF task during confinement in the mock POW camp and approximately 15 min after exposure to a highly stressful form of interrogation. Subjects completed the task after receiving the instructions noted above. The time point for stress assessment was selected based on our previous neuro-hormone data showing that this period of time coincides with robust increases in stress hormones (i.e., cortisol, NE, EPI, and NPY) and with significant decreases in gonadal hormones (Morgan et al 2000a, 2000b, 2001a). Subjects completed the ROCF task while in isolation and were monitored by the researchers (CAM, AD). The instructions and administration of the ROCF task was identical to the procedure described above.

Post-Stress Assessment (Recovery). Six hours after subjects' release from the mock POW camp, they assembled in the classroom and were readministered the CADSS. When completing the CADSS, subjects were instructed to use their experience during the stressful time in the mock POW camp as the reference point for their report. Once subjects had completed the CADSS, those randomized to the Pre-stress and Stress ROCF groups exited the room. Subject assigned to the Post-stress ROCF group remained seated and were administered the ROCF copy and recall tasks as described above.

Data Analysis

ROCF Data. The ROCF copy and recall figures were scored according to the Taylor scoring method (Taylor 1991). Scoring of the ROCF data was performed by a member of the research team who was blind to the conditions under which the ROCF data from any individual subject were collected (GH). The figures were also scored so as to indicate the approach used by the subject when doing the copy task. As noted by the color changes of the copy task, it was possible to determine the general approach to the task. If subjects initiated the task with the box component, or large components of the ROCF followed by the small internal details, the figure was scored as "box." If, on the other hand, the subject started completely on the left or right of the figure and worked his way across the figure in small increments, the figure was scored "left" or "right" accordingly.

To test whether exposure to stress significantly affected ROCF recall performance, a general linear model univariate analysis of variance (ANOVA) was used to compare ROCF recall scores (the dependent variable) among the three study groups (Pre-stress; Stress; Post-stress) (the fixed factor variable) (SPSS 11.5; SPSS Corporation, Chicago, Illinois). Post hoc analyses (Tukey) were conducted to detect where and how the groups differed from one another.

To test whether ROCF copy patterns were significantly different among the three study groups, cross-tabulation analyses (chi-square analyses) was performed using Style of copy (Box, Left, Right) and Group (Pre-stress; Stress; Post-stress) as the variables.

Assessment of Symptoms of Dissociation. General linear model ANOVA were used to assess whether exposure to the stress of survival school resulted in a significant increase in symptoms of dissociation (CADSS scores at baseline compared with CADSS scores post-stress). In addition, Pearson correlation analyses were performed to detect relationships between CADSS scores at baseline and CADSS scores at recovery.

Assessment of History of Trauma. Frequency data were tabulated and scored according to type of trauma exposure and whether DSM-IV criteria were met for traumatic stress exposure (DSM-IV-TR).

Assessment of Relationship between ROCF Recall and Dissociation. Pearson correlation analyses were used to assess the relationship between working memory performance on the ROCF and stress-induced symptoms of dissociation (CADSS post-stress) in the three study groups. Pearson correlation analyses were also used to examine the relationship between baseline CADSS and ROCF recall scores in the three study groups.

Assessment of Relationship between ROCF and History of Trauma. Independent *t* tests were used to examine whether ROCF recall scores (dependent variable) were significantly different between subjects who had and did not have previous exposure to traumatic stress ("fear for life" as the fixed factor). Pearson correlation analyses were used to examine the relationship between total number of trauma events and ROCF recall in each study group.

Assessment of Relationship between Dissociation and History of Trauma. To test whether we would replicate the findings of our previous studies, a general linear model ANOVA was performed using CADSS baseline and CADSS post-stress as the factors, and "exposure to traumatic stress (fear for life)" as the between group factor.

To test which variables best predicted ROCF recall performance during stress, linear regression analyses were conducted using the dependent variable ROCF recall during stress and the independent variables CADSS score at baseline and history of traumatic stress.

Results

ROCF Copy Data

The mean ROCF Copy scores for the Pre-stress, Stress, and Post-stress groups were 35.8, 33.4, and 35.4, respectively. General linear model univariate ANOVA indicated there was a significant effect of group ($F(1,2) = 52.04$; $p < .000$). Post hoc analyses (Tukey) indicated that this effect was due to a significantly lower ROCF Copy score in the Stress group (mean difference between

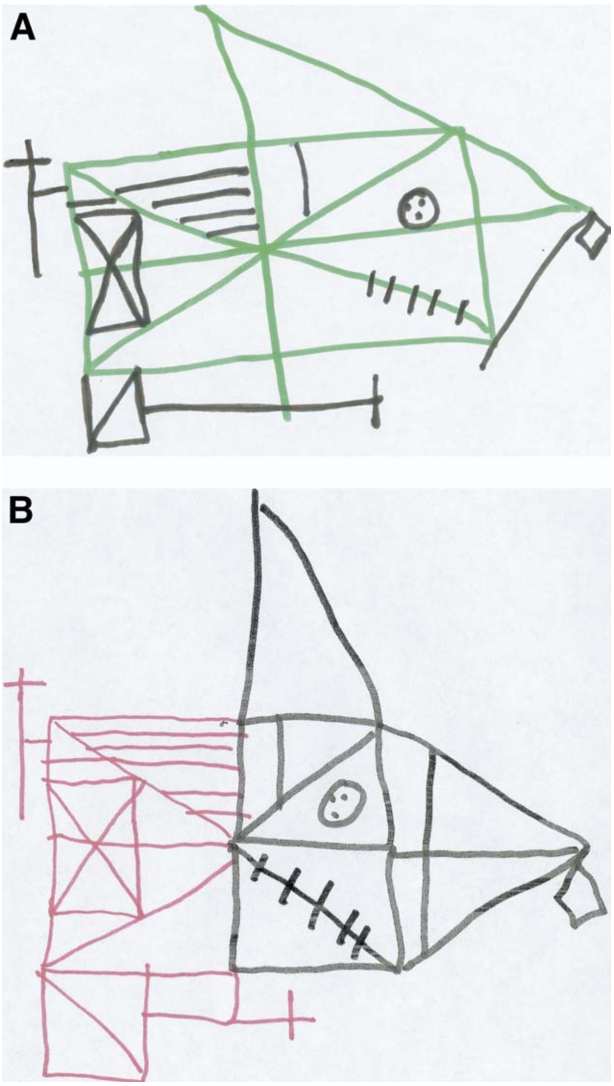

Figure 2. Sample ROCF Copy drawings from the **(A)** Pre-stress and Post-stress groups and from the **(B)** Stress Group. In the Pre- and Post-stress groups, subjects used a configurational approach as noted by the fact that the larger components of the figure are in green (the color of the first pen subjects used), whereas the smaller components are in black (the color of the second pen used by subjects 1 min after beginning the task). By contrast, subjects in the Stress group used a piecemeal strategy. As subjects worked bit by bit across the figure, when the pens were switched (from red to black), the piecemeal approach resulted in a bisected figure that is all red on one side and all black on the other.

Stress and Pre-stress group = 2.40 [standard error (SE) = .25]; $p <$ .001; mean difference between Stress group and Post-stress group = 1.98 [SE = .26]; $p <$ .001; mean difference between Pre-stress group and Post-stress group = .41 [SE = .25]; p = .25).

Cross-tabulation analyses indicated that of the 67 subjects in the Pre-stress group, 66 started their copy task with the Box and one subject started on the Right. Of the 62 subjects in the Stress group, 46 subjects started on the Left, 12 subjects started on the Right, and 4 subjects started with the Box. Finally, of the 55 subjects in the Post-stress group, 50 subjects started with the Box and 5 subjects started on the Left. Chi-square tests indicated that this difference in copy task style was significant (Pearson chi-square = 143.6; $p <$ .000). The differences in construction approaches are observed in Figure 2A and B. The switching of the color of the pens used by subjects reveals the differences in the construction approaches used by subjects. The configurational strategy resulted in an ROCF figure where the larger components of the figure (such as the rectangle) were drawn first (and in the color of the first pen given to subjects), whereas the smaller components (such as the circle or small lines) are drawn in the color of the second pen given to subjects. By contrast, subjects using the piecemeal strategy worked their way incrementally across the ROCF figure. When the color of the pen was switched, this resulted in the ROCF figure being bisected visually between the two colors of pens.

ROCF Recall Data

The mean ROCF recall scores for the Pre-stress group, Stress group, and Post-stress group were 32.8, 19.4, and 31.9, respectively. General linear model univariate ANOVA indicated there was a significant effect of group ($F(1,2)$ = 123.8; $p <$ .001). Post hoc analyses (Tukey) indicated that this effect was due to a significantly lower ROCF recall score in the Stress group (mean difference between Stress and Pre-stress group = 13.5 [SE = 94]; $p <$ .001; mean difference between Stress and Post-stress group = −12.6 [SE = .98]; $p <$ .001; mean difference between Pre-stress group and Post-stress group = −.93 [SE = .97]; p = 0.6). Figure 3A and B illustrate the typical differences in ROCF recall between the Stress group and the Pre or Post-stress groups.

As shown in Figure 4, Pearson correlation analyses indicated that for the Stress Group, there was a significant relationship between

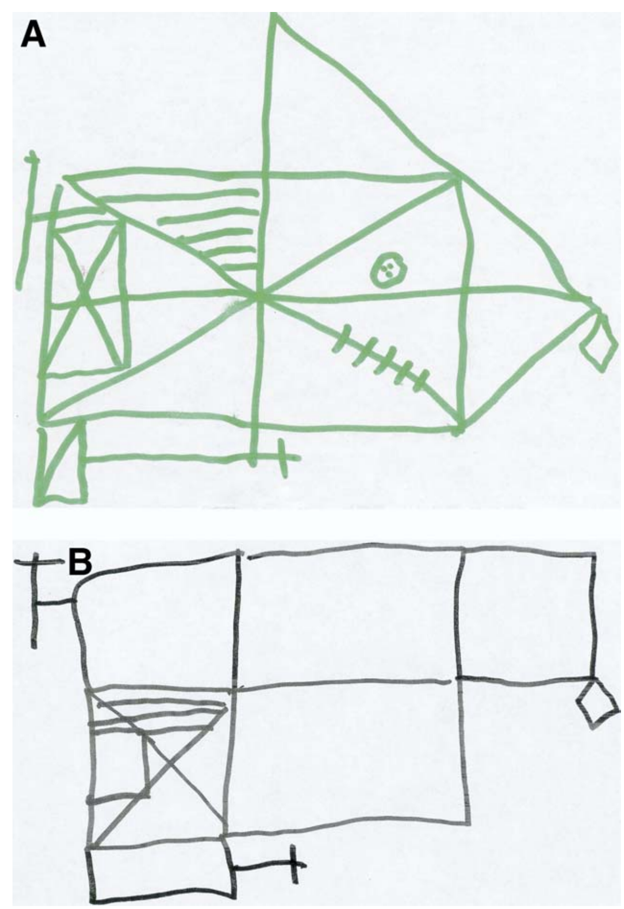

Figure 3. Sample ROCF immediate recall drawings from the **(A)** Pre/Post-stress groups and the **(B)** Stress Group. Immediate recall was significantly impaired in the Stress Group but not in the Pre- or Post-stress groups.

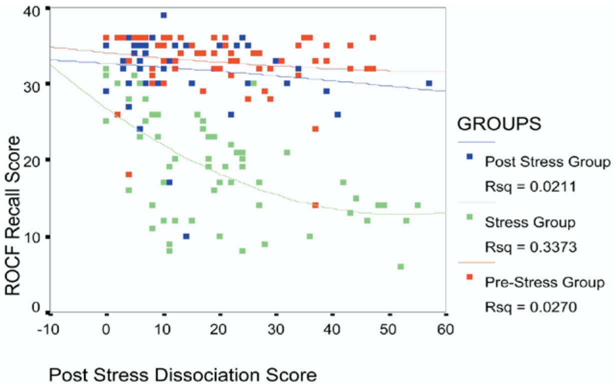

Figure 4. Relationship between ROCF recall and stress induced symptoms of dissociation. There was a significant, negative correlation between ROCF recall and stress-induced symptoms of dissociation in the Stress group (the green markers). No significant relationships were observed between symptoms of dissociation and ROCF recall in the Pre- or Post-stress groups (the red and blue markers, respectively).

ROCF recall performance and the stress-induced symptoms of dissociation ($r = -.56$; $p < .001$; $N = 62$). No significant relationship was observed between stress-induced symptoms of dissociation and ROCF recall performance in the Pre-stress or Post-stress groups.

Pearson correlation analyses also indicated there was a significant relationship between baseline (pre-stress) symptoms of dissociation and ROCF recall performance during stress (Stress group; $r = -.25$; $p < .05$; $N = 62$). No significant relationships were observed between baseline dissociation scores and ROCF recall performance scores in the Pre-stress or Post-stress groups of subjects.

No significant Pearson correlations were observed between ROCF performance and the variable "total number of potentially traumatic events." However, general linear model analyses of variance using ROCF recall as the dependent variable and traumatic stress exposure (i.e., subjects endorsed "fear for life" during exposure to event) as the fixed factor showed that exposure to traumatic stress significantly impaired ROCF recall performance during stress [$F(1,60) = 15.6$; $p < .001$].

Consistent with our previous investigations, exposure to the acute stress of survival school training resulted in a significant increase in symptoms of dissociation (baseline mean score = 3.4; SD = 5.2; Stress mean score = 17.7; SD = 13.4; $df = 1, 183$; $t = -17.7$; $p < .0001$). Significant within and between subject differences were observed [$F(1, 183) = 295$; $p < .0001$; $F(1,183) = 285$; $p < .0001$].

In addition, and as noted in Table 1, history of exposure to potentially traumatic events was common among subjects. History of exposure to traumatic stress was less common and observed in only 28% of subjects. History of exposure to traumatic stress was significantly associated with increased symptoms of dissociation at baseline [$F(1,183) = 12.1$; $p < .001$] and, after covarying for baseline dissociation scores, in response to stress [$F(1,183) = 61.6$; $p < .0001$]. These relationships were also noted when using Nominal by Interval (Eta) for status of "exposure to traumatic stress" and baseline symptoms of dissociation ($r = .25$; $p < .001$) as well as for "exposure to traumatic stress" and stress-induced symptoms of dissociation ($r = .40$; $p < .001$).

Relationship between Dissociation and History of Trauma in Predicting ROCF Performance

Linear general model regression analyses using "ROCF recall during stress" as the dependent variable and history of traumatic stress exposure (fear for life) and "pre-stress dissociation scores (CADSS)" as the independent variables indicated the Model was significant (R square = 21; Adjusted R square = 18; F change = 7.9; $df = 2$; $p < 0.002$). Standardized Beta coefficient for "history of traumatic stress exposure" was .42; $t = 3.4$; $p < 0.001$; the Beta coefficient for pre-stress dissociation score was $-.083$ and was not significant.

Discussion

Performance on the ROCF was within the normal range for the pre-stress and post-stress groups. However, exposure to realistic levels of acute stress resulted in significant alterations in both ROCF copy procedure and ROCF recall scores. Contrary to our hypothesis, nearly all subjects exhibited abnormalities in visuo-constructive abilities when copying the Rey figure immediately after stress exposure. The piecemeal strategy used by these adults resembles that observed in pre-pubescent children and is rarely used after the age of 9 years (Waber and Holmes 1985, 1986). Unlike the configurational approach that incorporates an broad gestalt view of the data or situation, the piecemeal strategy is narrow and detail focused, which is akin to seeing the "the trees rather than the forest" and may result in less-than-ideal decision making, particularly in situations that require a rapid assessment and integration of the "big picture."

Accurate and efficient visuo-spatial integration is essential for several critical military operational tasks, such as navigation. In a limited period of time, military personnel must be able to synthesize map details into a coherent, "big picture," mental representation of the area of operations. This ability allows them to rapidly determine their location as well as directions to various waypoints. A piecemeal strategy would significantly restrict an operator's field of vision or focus, limiting the ability to effectively execute these tasks. Within the current military context of warfare in congested urban environments, it seems likely that stress-induced deficits in complex mental operations, such as visuo-spatial organization, might result in significant navigational and operational errors (Belenky et al 2000).

The reduction in ROCF recall scores in the stress-group indicates that memory was adversely affected by exposure to acute stress. The 1-min delay interval suggests this reduction in ROCF recall scores reflects an impairment in working memory. Working memory refers to the capacity to retain and manipulate recently acquired information that one will rely on to execute cognitive operations

Table 1. Demographics Regarding History of Exposure to Trauma ($N = 184$)

Type of Trauma	No. of Subjects Endorsing Exposure to Event
War Zone Experience	17 (9.1%)
Life Threatening Accident	24 (12.9%)
Natural Disaster	31 (16.7%)
Life Threatening Illness	34 (18.3%)
Physical Abuse as Child	34 (18.3%)
Mugging or Assault as Adult	36 (19.4%)
Sexual Abuse as Child	22 (11.8%)
Other Type of Fearful Event	22 (11.8%)
Family Illness or Death	18 (9.7%)
Witnessed Threat or Injury	25 (13.4%)
Mean Total Number of Trauma = 1.6 (SD = 2.0)	
No. of Subjects Endorsing Fear for Life = 40 (21.7%)	
No. of Subjects Endorsing Physical Injury = 33 (17.9%)	

SD, standard deviation.

within a short period of time (Baddeley 1986). Within the context of battlefield activity, soldiers rely on working memory for several tasks. For example, when receiving and relaying target coordinates via radio communications, military personnel must use working memory to retain the sequence of numbers given to them that correspond to the grid locations on a map. An inability to do this task accurately may result in missing the enemy targets or even mistakenly bombing allies or one's own troops (i.e., friendly fire).

The ability to hold in mind and recall ROCF information is dependent, in large part, on the pre-frontal cortex (PFC), a region of the brain critical to "working memory." In both rats and monkeys, high levels of dopamine and NE turnover in the PFC have been shown to induce cognitive impairment, including deficits in spatial working memory (Arnsten 1997; Zahrt et al 1997). Consistent with these preclinical findings, subjects in the current study who were exposed to interrogation stress, a stimulus known to elicit high turnover of catecholamines, exhibited deficits on ROCF recall, a task dependent on intact spatial working memory.

ROCF performance was significantly poorer in subjects who reported greater histories of exposure to traumatic stress (threat to life). It is well known in preclinical studies that early exposure to uncontrollable stress can cause sensitization of noradrenergic and dopaminergic systems (Henry et al 1995). Such animals may respond to subsequent stress with enhanced catecholamine synthesis and release. Increased peripheral catecholamine release is thought to subsequently increase central arousal and NE turnover in the LC via activation of beta-adrenergic receptors located on afferent fibers of the vagus nerve that project to the nucleus of the solitary tract. Projections from the nucleus solitary tract then release NE in the amygdala (Introini-Collison et al 1992; Van Stegren et al 1998).

The locus coeruleus (LC) serves as a critical component of the brain's alerting or vigilance system (Aston Jones et al 1994). Acute stress-induced (or fear-induced) activation of the LC results in increased release of norepinephrine in multiple brain regions that are involved in perceiving, evaluating, and responding to potentially threatening stimuli (Redmond et al 1987). Noradrenergic projections from the LC modulate PFC functioning through postsynaptic alpha one and alpha two receptors. Preclinical research suggests that moderate basal release of NE improves PFC cognitive functioning through preferential binding to postsynaptic alpha 2 a receptors (Arnsten 1998a, 1998b). However, under conditions of high stress, NE release is increased above basal levels in the PFC and causes a decline in PFC functioning (Arnsten 1998a; Birnbaum et al 1999).

Analogously, clinical challenge studies have provided evidence for stress sensitization in individuals who have been exposed to uncontrollable stress (Morgan et al 1995; Bremner et al 1997). It has been suggested that exaggerated noradrenergic release in subjects with a sensitized SNS leads to an impairment in PFC and working memory (Southwick et al 1999). This impairment may explain the current finding that subjects with a history of traumatic stress exhibited poorer ROCF recall performance under stress, which may reflect the negative effects of heightened catecholamine turnover in the PFC.

The current study data were obtained from healthy subjects who demonstrated ROCF impairments in the absence of any known tissue insult. However, results from clinical studies of ROCF data in patients suffering from different patterns of neuropathology provide insight into some causes of impaired ROCF performance. Although ROCF copy and recall may be disrupted by significant tissue destruction in either hemisphere (Lezak 1995), most relevant to the current data are studies in which subjects' copy performance remained within normal limits but subsequent recall performance demonstrated impairment. Diamond and DeLuca (1996) reported a decline in ROCF performance in subjects after anterior communicating artery aneurysm. Similarly, fragmented approaches to copying the complex figure, and declines in ROCF recall, have been associated with both Parkinson's disease (Ogden et al 1990) and Huntington's disease (Fedio et al 1979). Janowsky and Thomas-Thrapp (1993) reported no significant difference in organizational strategy for elderly versus young subjects and concluded that impaired recall performance for the older group could not be accounted for by different construction/encoding strategies. Their findings suggest intact ROCF copy with impaired recall may occur from a range of causes: impaired attentional capacities, disruption of visual memory, and ineffective encoding of visual data secondary to inefficient encoding strategies at the copy phase. Perhaps most relevant to our study, Shin et al (2004) reported that impaired recall performance in patients with obsessive compulsive disorder. Controlling for anxiety, Shin et al concluded that the deficits were attributable to organizational deficits and poor visual memory functioning. They suggest that fronto-striatal or fronto-temporal dysfunction be responsible for the observed deficits (Shin et al 2004).

Stress-induced symptoms of dissociation were negatively related to ROCF recall scores in the stress group but not in the pre-stress or post-stress groups. Our previous research at Survival School has shown that such disturbances in perception and cognition are consistently associated with poorer military performance. These military performance ratings are restricted from the public; However, in general, it can be said that they assess how well a student can think clearly and communicate effectively when challenged by dilemmas while in mock confinement. These dilemmas require students to draw on (remember/recall) the didactic information they received 1 week earlier and to actively incorporate the information and apply it within a novel and stressful environment (Morgan et al 2000a, 2000b, 2001a, 2002, 2004). The current ROCF data increase our understanding as to how stress may specifically affect perception, cognition, and memory—all of which are necessary for optimal battlefield performance. Currently, little is known about the neuropsychological and biological mechanisms involved in symptoms of dissociation, per se; however, it is possible that dissociation, like altered ROCF recall during stress, reflects the consequences of high states of arousal (Morgan et al 2003).

We believe that the current findings may have direct implications for future research and for interventions designed to enhance a soldier's cognitive performance on the battlefield. The problems in working memory exhibited by subjects in this study seem most likely due to neurobiologically induced dysfunction of the PFC. Based on preclinical and clinical findings, it is likely that stress-induced deficits in working memory could be ameliorated by several approaches. For example, pharmacologic agents that prevent catecholamine release or block catecholamine receptors in the PFC would be expected to maintain optimal PFC functioning during stressful situations (Morgan et al 2003). Similarly, cognitive interventions that aim to facilitate cortical modulation of arousal (i.e., stress inoculation training) are likely to result in improved performance during stress (Gaab et al 2003).

Another implication of the current findings is that it may be possible to identify, in advance, individuals at increased risk for experiencing greater cognitive impairment during stress. People who reported a history of traumatic stress exposure and/or reported increased symptoms of dissociation at baseline were significantly more likely to exhibit diminished ROCF recall performance during stress. Early identification and intervention with this group of soldiers may decrease battlefield errors due to stress-induced declines in cognition and memory. It is also possible the current findings have relevance to civilian disaster relief work. During the initial phases of rescue operations, emergency service personnel may experience similar deficits and, as a result, commit cognitive errors that result in increased risk to themselves and to others. Future investigations designed to evaluate mishaps among rescue workers may clarify this issue.

There are several limitations to this study. First, it is possible the findings from the Stress Group were affected by the food and sleep deprivation experienced by subjects during training. However, this explanation of our findings is unlikely in that the subjects in the Post-stress group experienced a greater degree of food and sleep deprivation and yet the ROCF data were normal in the Post-stress group. This result suggests that the alterations in ROCF performance in the Stress-group are related to the impact of acute stress exposure rather than effects of prolonged sleep deprivation or food deprivation.

Another limitation in this study is that nearly all subjects in the Stress group resorted to a piecemeal strategy on the ROCF copy task. This restricted range of behavior prevented us from assessing whether piecemeal construction is linked to history of trauma or to dissociation. In future studies, identification of a larger sample of individuals who do maintain gestalt strategies under stress is needed to better understand this observation in relation to other biological variables of future interest (plasma NE, NPY etc.).

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